

EFFICIENCY TEST AND HEAT  
BALANCE OF A COMPOUND  
BELT AIR COMPRESSOR

G. F. VINCENT

1898

GE

TOWNE

378.748

POS 1898.4

REFERENCE



EFFICIENCY TEST  
AND  
HEAT BALANCE  
OF A  
COMPOUND BELT  
AIR COMPRESSOR

Vincent '98.

Air Compressor.

A  
88

*J. J. Vincent* '98.

5/30/98

1000 2000 3000 4000 5000 6000 7000 8000 9000 10000  
11000 12000 13000 14000 15000 16000 17000 18000 19000 20000  
21000 22000 23000 24000 25000 26000 27000 28000 29000 30000  
31000 32000 33000 34000 35000 36000 37000 38000 39000 40000  
41000 42000 43000 44000 45000 46000 47000 48000 49000 50000

51000 52000 53000 54000 55000 56000 57000 58000 59000 60000  
61000 62000 63000 64000 65000 66000 67000 68000 69000 70000  
71000 72000 73000 74000 75000 76000 77000 78000 79000 80000  
81000 82000 83000 84000 85000 86000 87000 88000 89000 90000  
91000 92000 93000 94000 95000 96000 97000 98000 99000 100000

101000 102000 103000 104000 105000 106000 107000 108000 109000 110000  
111000 112000 113000 114000 115000 116000 117000 118000 119000 120000  
121000 122000 123000 124000 125000 126000 127000 128000 129000 130000  
131000 132000 133000 134000 135000 136000 137000 138000 139000 140000  
141000 142000 143000 144000 145000 146000 147000 148000 149000 150000

151000 152000 153000 154000 155000 156000 157000 158000 159000 160000  
161000 162000 163000 164000 165000 166000 167000 168000 169000 170000  
171000 172000 173000 174000 175000 176000 177000 178000 179000 180000  
181000 182000 183000 184000 185000 186000 187000 188000 189000 190000  
191000 192000 193000 194000 195000 196000 197000 198000 199000 200000

201000 202000 203000 204000 205000 206000 207000 208000 209000 210000  
211000 212000 213000 214000 215000 216000 217000 218000 219000 220000  
221000 222000 223000 224000 225000 226000 227000 228000 229000 230000  
231000 232000 233000 234000 235000 236000 237000 238000 239000 240000  
241000 242000 243000 244000 245000 246000 247000 248000 249000 250000

251000 252000 253000 254000 255000 256000 257000 258000 259000 260000  
261000 262000 263000 264000 265000 266000 267000 268000 269000 270000  
271000 272000 273000 274000 275000 276000 277000 278000 279000 280000  
281000 282000 283000 284000 285000 286000 287000 288000 289000 290000  
291000 292000 293000 294000 295000 296000 297000 298000 299000 300000

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378.748  
POS 1898.4

# Brief Index.

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4 June 48. Ser. 9. 6. 1. 9. 2.



The object of the experiments was to determine data for computing the efficiency of the compressor, and for the calculation of a heat balance.

### Description of Machine.

The Machine is known as a compound belt driven air compressor, style no. 1, manufactured by the Pedrick & Ayer company of Philadelphia. It is a part of the installment of experimental apparatus in the Department of Mechanical Engineering, of the University of Pennsylvania. Fig. 1, ~~1/11~~ gives a sectional view. *c* is the base supported on four iron legs. To it are bolted the cylinder



casting d the outboard bearing  
g and underneath, the  
valve chest e. To the cylinder  
casting is bolted the bearing  
standards carrying the  
shaft f. The two cranks  
are at  $180^{\circ}$ . The shaft  
carries the loose pulley a  
and the driving pulley b  
the latter being a fly-wheel.

The air is taken in through  
the valves j to the low  
pressure cylinder h.

Discharged through the  
valves k, through the  
small chamber v and  
the valves l to the high  
pressure cylinder i. Thence  
by valves m to the off-flow  
pipe n. A water jacket surrounds



the chamber *v* and both cylinders. The valves *j* and *k* act by gravity and *l* and *m* by spring.

The pipe *n* leads to a receiver. In practical use this receiver should have a volume of about fifty cubic feet. As the object of the receiver in the experiment was simply to steady the pressure a much smaller one was used. It consisted of a length of 10" steam pipe flanged at each end with blanks bolted on. In the top blank was led the pipe from the machine  $1\frac{1}{4}$ " diameter, a return pipe to the belt



shifter  $\frac{1}{2}$ " diameter and a 1" lead off pipe containing a throttle valve. In this pipe was led a  $\frac{1}{4}$ " pipe for a pressure gauge. The pressure in the receiver was regulated by the throttle valve. To the bottom of the receiver was led a  $\frac{1}{2}$ " pipe with a valve. This was used to blow off the moisture in the receiver. A thermometer cup was placed in the supply pipe from the machine.

The belt shifter above mentioned is not shown in the print. It consists of a valve of the safety valve type having a lever



with a movable weight.  
The half inch pipe (page 4)  
was led to the under side  
of this pipe so that the  
valve would rise or fall  
as the pressure in the  
receiver rose or fell above  
a certain pressure deter-  
mined by the position of  
the sliding weight on the  
lever. The movement of  
the lever moved a slide  
valve in a small air  
engine, always in connection  
with the under side of the  
valve. This engine in turn  
moves a belt shifter which  
moves the belt from the  
fast to the loose pulley or  
vice-versa. The connections



of the valve rod to the lever are so arranged that the lifting of the valve shifts the belt from the fast to the loose pulley.

The inlet and outlet for the water jacket are indicated in the figure.

The inlet pipe contained a valve and a thermometer cup. The outlet contained a thermometer cup and led to a tank on scales by which the jacket water could be weighed.

Indicator taps were led into the cylinders as shown by the dotted lines o and p. The indicators were placed





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**PEDRICK & AYER CO.**  
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AND APPLIANCES,  
1001 AND 1003 HAMILTON ST.,  
PHILADELPHIA, PA.

----- SCALE IN'S. TO A FOOT.

is made that the lifting  
the valve shifts the belt  
from the fast to the loose  
pulley. The inlet and  
outlet.



horizontally at *g*. The end of the shaft was drilled and tapped and the light crank *r* screwed on. The crank arm contains the two grooves *s* and *t*. The groove *s* carried the counter cord and the groove *t* the indicator cords.

#### Action of the Machine.

Consider the low pressure piston all the way down and the machine starts.

Air flows in through *j* until the piston reaches its highest point. The low pressure piston starts down and the high pressure starts up. If there were no pressure in the receiver *v*



the valves  $k$  and  $l$  would open at once. But the small clearance volume in the high pressure cylinder contains air at the pressure of the receiver and the chamber  $v$  contains air at a pressure equal to the highest pressure obtained in the low pressure cylinder. So neither valve opens at once. When the air in the clearance volume expands to a pressure equal to the pressure in  $v$  the valve  $l$  opens and the air in  $v$  goes on expanding into the high pressure cylinder as it moves up.

So the pressure of the air in  $v$  decreases while



the pressure in the low pressure cylinder is increasing as the piston comes down. Finally a point is reached where the pressure in  $h$  becomes greater than the pressure in  $v$  and the valve  $k$  opens. This occurs when the low pressure piston is about half-way down and the high pressure consequently half way up. Then the low pressure piston goes on compressing air into the chamber  $v$  and the high pressure cylinder until the end of the stroke. Then the return commences; the valves  $k$  and  $l$  close and the valve  $j$  opens as before. The



high pressure piston goes on compressing its charge of air to the pressure of the receiver when the valve *m* opens and the air is pushed out into the pipe *n*.

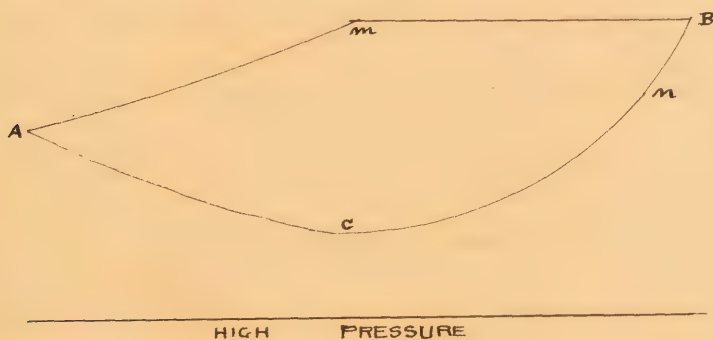


FIG. 2.

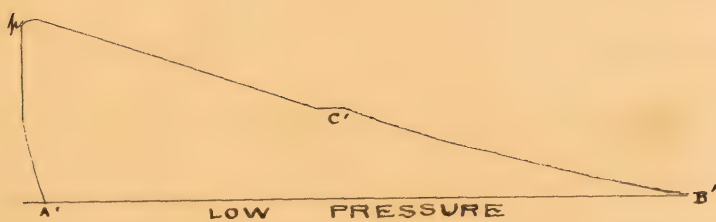


Fig. 2 shows two characteristic cards. Valve *j* opens at A' (page 8.) At B' the low pressure piston



is at the upper end of its stroke and the high pressure at B is at the lower end of its stroke. At n the valve l opens (page 9\*). At e and c the valve k opens (page 10\*). At A the high pressure reaches the highest point on its stroke and p the low pressure piston is at its lowest point. At m the valve m opens (page 11\*).

### The Power Scale.

The Compressor was belted to a pulley by a five inch belt. This pulley is driven by an Emerson Power Scale. It was proposed to determine with this scale the power delivered to the machine. Subsequent conditions made



this impossible, and the power scale was used in another manner. Fig. 3 shows

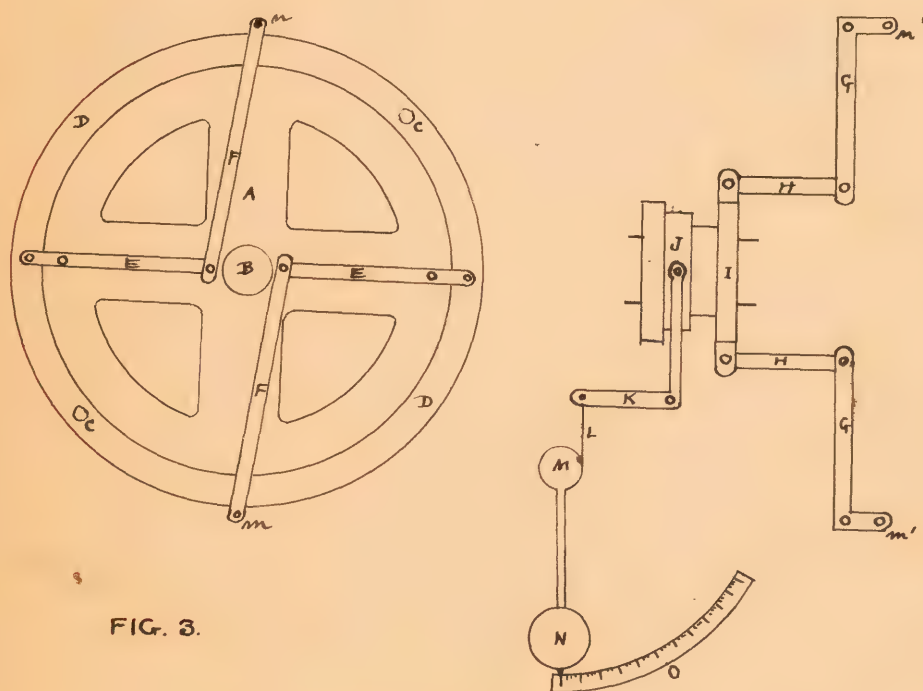


FIG. 3.

the general principle of the instrument. It consists of the disk A keyed to the shaft. On this, upon frictionless



rollers is placed the collar  
D which carries two pins c, c.  
These pins drive the pulley  
which rides loose on the  
shaft. The slight movement  
of the disk under the collar  
when transmitting power  
moves the fulcrums of the  
levers E, E, and the levers  
F, F. The movement tends  
to displace the points m and  
n from the shaft. The points  
m and n, and m' and n',  
correspond. The outward  
motion of m' and n' cause  
the bell-crank levers G, G,  
acting through H, H, to pull  
the sheave I along and  
with it the loose collar J.  
This collar does not revolve



It carries the bell-crank *x* which by unwinding the chain *L* on *M* causes the pendulum pointer *x* to be deflected over the scale *o*. The scale, ~~and~~ the fulcrums of the bell-crank and pendulum are on a frame carried by another loose collar not shown in the figure. So that while the machine as a whole revolves the registering part hangs still.

#### Other Instruments.

Barometer for determining the pressure of the air.

Five thermometers.

Two Aschroft Indicators.

One Pressure Gauge.



## Method of Conducting Tests.

It was first proposed to run tests of one hour duration. The bearings of the machine heated up so rapidly that these tests were reduced to one half hour and later to twenty minutes. The machine had to be kept running some time to allow temperatures to become constant.

Three tests were run. One with the pressure in the receiver at about eighty pounds, one at about seventy pounds and one at about sixty pounds.

Readings were taken every-five minutes and



four cards were taken each run, that is four cards from each cylinder.

### Readings.

Time.

C - Revolution counter on machine

P.S. Deflection of Power Scale

P - Pressure in receiver

$t_{in}$  - Temperature of water flowing into jacket.

$t'_{in}$  - Temperature of water flowing out of jacket into tank.

$T_r$  - Temperature of air flowing into receiver.

$H_b$  - Barometrical height.

$T_o$  - Temperature of the outside air.

$T_a$  - Temperature of air



11 in room where tests were conducted.

Time of the tank empty and weight of same.

Time of the tank full and weight.

Reading of counter on power scale and exact time of this reading at intervals throughout the test.

The counter being read exactly every five minutes the differences of the counter readings divided by 5 gave the revolutions per minute =  $N$

The deflection of the power scale and the reading



of the counter are not used in the calculations for the following reason:- As stated above it was proposed to use the scale to determine the power put into the machine. A curve of constants had been determined by a previous experimenter, and by using these constants it was thought that the power could be calculated. The results obtained were out of the question giving efficiencies of over and nearly a hundred percent.

Then it was proposed to run the machine at no load, taking cards and the deflection of the



scale and assume that the difference of the power of the scale and that of the cards represented the friction of the machine.

This assumption that the friction is a constant quantity is fair enough as the conditions under which the friction power was determined were made as nearly like the conditions of the test as possible, and further the conditions of the three tests were quite similar. But the method stated, using constants from the curve, gave more impossible results, and another scheme



was resorted to. The valves of the low pressure cylinder were propped open, and the machine run with no pressure in the receiver as before. Cards were taken and revolutions of the machine; also deflection of the power scale and revolutions. Then the power scale was calibrated at once at that deflection.

And this power minus the power from the cards gave a friction load which was probable and fair.

It was impossible to calibrate the power scale at the high deflections of the test, first, on account



of lack of immediate facilities and second, on account of the lack of time.

The temperatures of the air inside and outside were taken for the reason that the relative humidity outside was a hundred percent and knowing the two temperatures the relative humidity could be obtained inside for use in the heat balance.

The times and weights empty and full of the tanks being known the difference of weights divided by the differences of times gives the weight per minute,  $= M_w$

The method of obtaining



the revolutions of the power scale is interesting. The number of revolutions in a half minute were taken accurately with the watch, and hence the number in one minute. The automatic counter on the scale made one revolution for every hundred revolutions of the shaft and was divided into one hundred parts.

At intervals of exactly ten minutes, the position of the pointer was read. The number of revolutions in ten minutes would be given roughly by multiplying the number in one minute by ten. This added to the first reading



should give a number near the second reading. This being the case the difference between the second and the first reading together with the number of complete revolutions in the time was taken and divided by ten which gave the exact number of revolutions per minute.

These readings are omitted from the data, but the results are -

First test - 212.01

Second test - 211.33

Third test - 211.55.

Determination of the Friction Constant of the Machine.

The card given by the



low pressure cylinder was a straight line along the atmospheric line, no area.

The card given by the high pressure is given in Fig 4, inked in. The

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AREA - 26

LENGTH-448

FIG. 4.

deflection of the power scale was - 17.

The calibration of power scale was made by means of a brake of the pulley.

The brake consisted of a leather belt hung over the pulley, equally long on both sides. One end was attached to a spring balance which was



hooked to a fifty pound weight on the floor for stability. To the other end was hung a scale hook with weights. As the wood pulley exhibited a tendency to burn, the calibration had to be made rapidly. The weights could not be added and subtracted one at a time but changed and added in a bunch, with time left between for cooling. The scale of the power scale was watched while an assistant changed the weights. A deflection of just 17 was obtained when there was 6 pounds on the



one side with a pull on the balance of 40 pounds on the other. The belt weights on either side were equal. The speed of the scale was 212 revolutions per minute and of the compressor 125 revolutions

High pressure cylinder constant,-

Diameter cylinder = 6"

Stroke = 6"

$$\text{Constant} = \frac{6^2 \times \frac{\pi}{4} \times \frac{1}{2}}{33000} = .000428$$

Spring scale = 54.19 (page 33)

Work from card of

Fig 4,-

$$\frac{.26 \times 54.19 \times .000428 \times 125}{4.48} = .1683 \text{ HP}$$

The diameter of the pulley



was 2'

Work from scale calibration,

$$Wt = 40 - 6 = 34 \text{ lb}$$

$$\frac{34 \times 212 \times 2 \times 3.1416}{33000} = 1.37 \text{ HP}$$

$$\text{HP of friction} = 1.37 - .168 = 1.202 \text{ HP}$$

Low Pressure Cylinder  
Engine Constant -

$$\text{Diameter} = 11 \text{ "}$$

$$\text{Stroke} = 6 \text{ "}$$

$$\text{Constant} = \frac{11^2 \times \frac{\pi}{4} \times \frac{1}{2}}{33000} = .00144$$

Calibration of Pressure  
Gauge.

The Croebly oil gauge  
tester was used. Readings  
were taken on the gauge  
at every five actual pounds  
as the pressure was increased



and diminished. The mean of a pressure increasing and of the corresponding one decreasing gives the correct reading of the gauge. The results of this test and the readings are given in table 1.

#### Calibration of Indicator Springs.

A 30<sup>th</sup> spring was used in the low pressure indicator and a 50<sup>th</sup> in the high pressure. Immediately after finishing the tests the indicators were placed on the tests and tested using the gauge which had just been calibrated. Cards were put on the



Table No. 1.  
Gauge Calibration.

| Actual<br>Pounds | Gauge reading<br>Going up | Gauge reading<br>Going down | Gauge reading<br>Mean |
|------------------|---------------------------|-----------------------------|-----------------------|
| 10               | 11                        | 13.5                        | 12.25                 |
| 15               | 16                        | 18.5                        | 17.25                 |
| 20               | 21                        | 23.5                        | 22.25                 |
| 25               | 26                        | 28.5                        | 27.25                 |
| 30               | 31                        | 33                          | 32.                   |
| 35               | 36                        | 38                          | 37.                   |
| 40               | 41                        | 43                          | 42.                   |
| 45               | 46                        | 48                          | 47.                   |
| 50               | 51                        | 53                          | 52.                   |
| 55               | 56.5                      | 58                          | 57.25                 |
| 60               | 61.5                      | 62.5                        | 62                    |
| 65               | 66.5                      | 67.5                        | 67                    |
| 70               | 72                        | 73.                         | 72.5                  |
| 75               | 77                        | 78.                         | 77.5                  |
| 80               | 82.5                      | 83.5                        | 83                    |
| 85               | 87.5                      | 88.5                        | 88                    |
| 90               | 92.5                      | 93.5                        | 93                    |



the drum and the steam gradually turned on. When the gauge reached the corrected pressure a line was marked on the card.

The card was then reversed and the steam gradually shut down and lines marked as before. The lines were marked at every ten pounds. The differences between each line and the next were measured going up and the corresponding difference going down.

The mean of <sup>each pair of</sup> these divided into ten pounds and the mean of these means were computed. This is the correct spring scale.



The data and results of these calibrations are given in tables 2 and 3.

Table No 2.

Calibration of 30<sup>th</sup> Spring.

| Gauge Readings | Difference in inches going up | Difference in inches going down | Mean of Differences | Pounds per inch |
|----------------|-------------------------------|---------------------------------|---------------------|-----------------|
| 12.25 to 22.25 | .35                           | .34                             | .345                | 29.             |
| 22.25 to 32.   | .35                           | .38                             | .365                | 27.4            |
| 32 to 42       | .34                           | .34                             | .34                 | 29.5            |
| 42 to 52       | .37                           | .36                             | .365                | 27.4            |

Table No 3.

Calibration of 50<sup>th</sup> Spring.

| Gauge Readings | Difference in inches going up. | Difference in inches going down | Mean of Differences | Pounds per inch. |
|----------------|--------------------------------|---------------------------------|---------------------|------------------|
| 12.25 to 22.25 | .19                            | .185                            | .1875               | 53.3             |
| 22.25 to 32    | .185                           | .195                            | .19                 | 52.6             |
| 32 to 42       | .19                            | .195                            | .1925               | 52.0             |
| 42 to 52       | .17                            | .185                            | .1775               | 56.4             |
| 52 to 62       | .15                            | .20                             | .175                | 57.1             |
| 62 to 72.5     | .165                           | .175                            | .17                 | 58.9             |
| 72.5 to 83     | .19                            | .19                             | .19                 | 52.6             |
| 83 to 93       | .205                           | .19                             | .1975               | 50.6             |



The mean of the Pounds per inch' column of the 30<sup>#</sup> spring was;

$$28.325 = \text{spring scale}$$

For the 50<sup>#</sup> spring it was;

$$54.19 = \text{spring scale}$$

### First Test.

Means Cards - Fig 5.

Data - Table A.

Mean results (symbols pgs. 17-18)

$$R = 117.5 \text{ per minute}$$

$$P.S. = 143.8 \text{ divisions}$$

$$P = 81.3^{\#} \text{ corrected} = 78.6^{\#}$$

$$t_w = 74.8^{\circ}$$

$$t'_w = 91.14^{\circ}$$

$$T_R = 175.6^{\circ}$$

$$H_G = 29.7192''$$

$$T_o = 60^{\circ}$$

$$T_a = 69.4^{\circ} \text{ corrected} = 70.9^{\circ}$$

Note. This thermometer read  $1.5^{\circ}$  low



$m_w$  = weight of water  
through jacket per  
minute  
= 5 #

Date of Test May 26, 1898.  
Duration of Test 20 minutes.

Indicated Horsepower.

HP = Mean height of card x  
spring scale x no of  
revolutions x engine constant

Mean height of card =  
area  $\div$  length.

From the cards of  
Fig 5 and the constants of  
pages 27 and 28 and scales pg 33.

High pressure HP =

$$\frac{2.93 \times 54.19 \times .000428 \times 1175}{4.44} = 1.795$$







Table 4.  
Readings of First Test.

| Time<br>P.M. | Counter<br>C | Power<br>Scale<br>P.S | Pressure<br>P | t<br>t <sub>w</sub> | t'<br>t <sub>w</sub> | T<br>of air<br>T <sub>a</sub> | Barometer<br>Hg | T<br>inside outside<br>therm. therm.<br>T <sub>a</sub> T <sub>o</sub> | Time<br>Tank     | Weight<br>Tank |
|--------------|--------------|-----------------------|---------------|---------------------|----------------------|-------------------------------|-----------------|-----------------------------------------------------------------------|------------------|----------------|
| 12.25        | 73426        | 144                   | 81.5          | 75                  | 88                   | 174                           | 29.722          | 69.5                                                                  | Empty<br>12.13.5 | 675            |
| 12.30        | 74015        | 144                   | 81.           | 75                  | 90                   | 175                           | 29.720          | 69.5                                                                  |                  |                |
| 12.35        | 74604        | 143                   | 80.5          | 75                  | 92                   | 177                           | 29.718          | 69.5                                                                  |                  |                |
| 12.40        | 75194        | 144                   | 81.5          | 75                  | 93                   | 178                           | 29.718          | 69.5                                                                  |                  |                |
| 12.45        | 77781        | 144                   | 82            | 74                  | 94                   | 177                           | 29.718          | 69                                                                    | Full<br>12.3.5   | 925            |



# MEAN CARDS FIRST RUN



HIGH PRESSURE

AREA-2.93

LENGTH-4.44



LOW PRESSURE

AREA-3.60

LENGTH-4.40



Low Pressure HP =

$$\frac{3.60 \times 28.32 \times .00144 \times 117.5}{4.40} = 3.92$$

Total Indicated HP =

$$1.795 + 3.920 = 5.715$$

Adding the friction page 28

$$5.715 + 1.202 = 6.917 \text{ HP}$$

$$\text{Efficiency} = \frac{5.715}{6.917} \times 100 = 82.6\%$$

Second test.

Mean Cards - Fig 6

Data - Table 5.

Mean results symbols page 17-18.

$n = 122.2$  per min.

P.S. = 126.8 divisions.

$P = 60.9''$  corrected  $58.9''$

$t_w = 72^\circ$

$t'_w = 88.1^\circ$



$$T_r = 170.6^\circ$$

$$H_t = 29.7036''$$

$$T_o = 60^\circ$$

$$T_a = 69.4^\circ \text{ corrected} = 70.9$$

$$m_{wv}(\text{pg. 34}) = \left\{ \begin{smallmatrix} 8.0904 \\ 4.14 \end{smallmatrix} \right\} \text{ per minute.}$$

Date of test May 26, 1898.

Duration of test 20 minutes.

Indicated Horse-power.

Carde. Fig 6

Constants pgs 27-28.

Scales pg 33.

Method pg 34.

High Pressure HP =

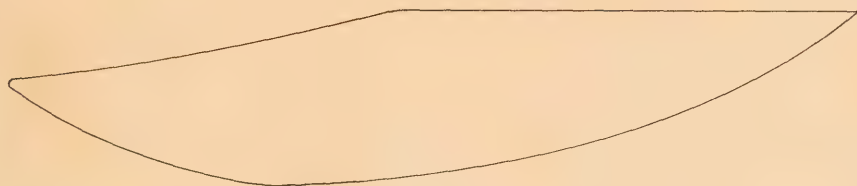
$$\frac{2.53 \times 122.2 \times 54.19 \times .000428}{445} = 1.61 \text{ HP}$$

Low Pressure HP =

$$\frac{3.21 \times 122.2 \times 28.32 \times .00144}{4.42} = 3.61$$

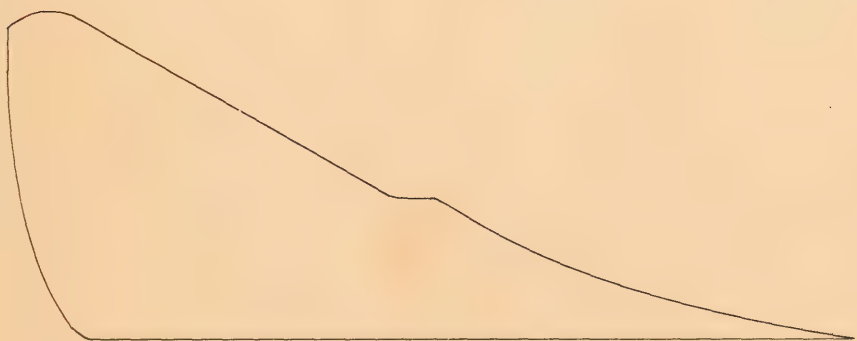


MEAN CARDS SECOND RUN



HIGH PRESSURE

AREA-2.53      LENGTH 4.45



LOW PRESSURE

AREA-3.21      LENGTH-4.42

FIG. 6



Table 5.

Readings of Second Test.  
 Symbols same as Table 4.

| Time<br>P.M.<br>line min | C     | P.S. | P    | t <sub>w</sub> | t' <sub>w</sub> | T <sub>r</sub> | H <sub>h</sub> | T <sub>a</sub> | T <sub>o</sub> | Chime<br>Tank                                          | Weight<br>Tank |
|--------------------------|-------|------|------|----------------|-----------------|----------------|----------------|----------------|----------------|--------------------------------------------------------|----------------|
| 1 45                     | 78798 | 129  | 61   | 73             | 87.5            | 168            | 29.706         | 69             | 60             | empty<br>(3) hr 37 <sup>m</sup><br>1 hr 7 <sup>m</sup> | 725            |
| 1 50                     | 79410 | 127  | 61.5 | 72             | 88              | 171            | 29.704         | 69.5           | 60             |                                                        |                |
| 1 55                     | 80020 | 126  | 61   | 71             | 88              | 172            | 29.704         | 69.5           | 60             |                                                        |                |
| 2 00                     | 80631 | 126  | 60   | 72             | 88.5            | 172            | 29.704         | 69.5           | 60             |                                                        |                |
| 2 05                     | 81242 | 126  | 61   | 72             | 88.5            | 170            | 29.700         | 69.5           | 60             | full<br>2 hr 11 <sup>m</sup>                           | 1000           |



Total Indicated HP

$$= 1.61 + 3.61 = 5.22 \text{ HP}$$

Adding friction pg. 28

$$5.22 + 1.202 = 6.422 \text{ HP}$$

$$\text{Efficiency} = \frac{5.22}{6.422} * 100 = 81.2 \%$$

Third Test

Mane Carde - Fig 7

Data Table 6.

Mean results symbols (pgs 17-18)

$$n = 1.21 \text{ rev. per minute.}$$

$$P.S. = 137.4 \text{ divisions}$$

$$P = 71.7^\# \text{ corrected } 69.3^\#$$

$$t_w = 73^\circ$$

$$t'_w = 914^\circ$$

$$T_r = 177^\circ$$

$$H_b = 29.696''$$

$$T_o = 60.4^\circ$$

$$T_a = 69.5^\circ \text{ corrected} = 71^\circ$$



$m_w = 4.13^{\text{th}}$  per minute

Date of Test May 26, 1898.

Duration of Test 20 minutes

Indicated Horse-power  
Cards Fig. 7, Constants pg. 21-28  
Spring scale pg 33, method 34,  
High pressure HP =

$$\frac{2.86 \times 54.19 \times 121 \times .000428}{446} = 1.80$$

Low Pressure HP =

$$\frac{3.56 \times 121 \times 28.32 \times .00144}{442} = 3.79$$

Total Indicated HP

$$3.79 + 1.80 = 5.59 \text{ HP}$$

Adding friction pg 28

$$5.59 + 1.202 = 6.792 \text{ HP} = \text{total}$$

$$\text{Efficiency} = \frac{5.59}{6.792} \times 100 = 81.9\%$$



# MEAN CARDS THIRD RUN



HIGH PRESSURE  
AREA-2.86 LENGTH 4.46



LOW PRESSURE  
AREA-3.56 LENGTH-4.42

FIG 7



Table 6.  
 Readings of Third Test.  
 Symbols same as Table 4.

| Time<br>P.M.<br>hr. m. | C     | P.S. | P <sub>co</sub> | t <sub>ur</sub> | t <sub>ur</sub> ' | T <sub>h</sub> | H <sub>h</sub> | T <sub>h</sub> | To   | Time<br>Yank     | Weight<br>Yank |
|------------------------|-------|------|-----------------|-----------------|-------------------|----------------|----------------|----------------|------|------------------|----------------|
| 2 45                   | 84106 | 136  | 73              | 73              | 89                | 174            | 29696          | 69,5           | 61   | empty<br>2hr 16m | 820            |
| 2 50                   | 84710 | 137  | 71,5            | 73              | 90                | 176            | 29698          | 69,5           | 60,5 |                  |                |
| 2 55                   | 85314 | 138  | 70,5            | 73              | 92                | 177            | 29694          | 69,5           | 60   |                  |                |
| 3 00                   | 85919 | 137  | 71,5            | 73              | 93                | 178            | 29696          | 69,5           | 60   |                  |                |
| 3 5                    | 86526 | 139  | 72              | 73              | 93                | 180            | 29696          | 69,5           | 60,5 | full<br>3hr 8m   | 1035           |



The mean cards given in Fig 5, 6, & 7 ~~pro~~ were obtained from the four pairs of cards taken in each run.

The indicator rig on the machine was not a correct one. It was corrected by placing cards on the drums, the indicators being in the exact position used during the test. Starting with the low pressure cylinder, it was set at its lowest point and then moved around so that the piston moved through  $\frac{1}{10}$  of its stroke at a time. This was determined by means of a steel rule. At each tenth a point was



marked with the pencil on the low pressure card. The operation was then repeated on the high pressure cylinder.

These points were laid off respectively on the four low pressure and the four high pressure cards, and ordinates erected. The mean length of each four was taken, laid off on the drawing board and divided into ten equal parts and ordinates erected. On each of these ordinates was laid off the mean of the four corresponding ordinates of the cards. Through the resulting series of points the mean card was drawn.



# Heat Balance of First Test.

Symbok pgs 17-18.

$$H_b = 29.7192$$

$P_o$  = Atmospheric pressure in  
pounds per sq. ft

$$= 14.08 \times 29.7192 \times 144 = \underline{2100}^{\#}$$

$V_a$  = volume of air per minute  
in the low pressure  
cylinder in cu. ft.  
 $= \text{vol cyl} \times r$

$$= \frac{11^2 \times \frac{\pi}{4} \times 6 \times 117.5}{1728} = \underline{38.7} \text{ cu ft.}$$

$R_1$  = Relative humidity of outside  
air = 100% (raining)

$$T_o = 60 \text{ absolute} = 521$$

$$T_a = 70.9 \text{ absolute} = 532$$

$R_2$  = Relative humidity at  
temperature  $T_a = \frac{T_o}{T_a} \times R_1$   
 $= \frac{521}{532} \times 100 = 98\%$

$h_1$  = pressure from steam tables  
corresponding to  $T_a = \underline{3725}^{\circ} \text{ per sq. in.}$



$p$  = Pressure at humidity  $R_2$

$$= .3725 \times .98 = .366''$$

$T_s$  = temperature corresponding to  
 $p$  = temperature of saturation  
 $= \underline{70.5^\circ}$

$P_a$  = Pressure of air on entrance  
 $= P_t - (144 \times p)$   
 $= 2100 - (144 \times .366) = \underline{2047''}$  per sq ft

$h_a$  = heat in the air on entrance  
taken above  $32^\circ$ , or  $493^\circ$  abs.  
 $= \frac{P_a \times V_a}{.41 \times 778} \left(1 - \frac{493}{532}\right)$   
 $= \frac{2047 \times 38.7}{.41 \times 778} \left(1 - \frac{493}{532}\right)$   
 $= \underline{13.53 \text{ B.T.U.}}$

$h_v$  = heat in vapor on entrance.  
(Water per cu. ft. =  $\gamma_v \times \frac{T_s}{T_a}$  (absolute))  
 $=$  almost exactly  $\gamma_v$ .

$$h_v = V_a \times \gamma_v \left[ \gamma_v + P_v + .369(T_a - T_s) \right]$$

$.369$  = specific heat at  
constant volume.

$$h_v = 38.7 \times .001148 \left[ 38.6 + 1006 + .369(70.9 - 70.5) \right]$$



$$h_w = \underline{46.5 \text{ B.T.U.}}$$

$$\begin{aligned} H_w &= \text{heat in jacket water} \\ &= (q_{ti} - q_{tw}) m_w \\ &= (59.1 - 42.9) 5 = \underline{81 \text{ B.T.U.}} \end{aligned}$$

$H_e$  = Work done by air on entrance is 0 as the pressure on both sides of the piston is equal.

$$\begin{aligned} H_2 &= \text{heat in indicated work} \\ &= \frac{\text{Indicated HP} \times 33000}{778} \\ &= \frac{5.715 \times 33000}{778} \\ &= \underline{242.5 \text{ B.T.U.}} \end{aligned}$$

$$\begin{aligned} H_a &= \text{heat in air at end} \\ &\quad \text{above } 493^\circ \text{ absolute.} \\ &= \frac{m R}{41 \times 778} (T_r - 493) \end{aligned}$$

$m$  = mass of air going through machine per minute =  $\frac{P_a V_a}{R T_a}$

$$H_a = \frac{P_a V_a}{T_a \times 41 \times 778} (T_r - 493)$$



$$= \frac{2047 \times 38.7 \times 143}{532 \times .41 \times 778} = 66.7$$

$$H_a = \underline{66.7} \text{ B.T.U.}$$

$H_v$  = heat in vapor at end.

$m_v$  = mass of vapor

$$= V_a \times \gamma_p = 38.7 \times .001148$$

$$= .0445 \text{ #}$$

$V_r$  = volume air per minute in the receiver

$$V_r = \frac{m R T_r}{P_r} \quad P_r \text{ in # per sq ft.}$$

$$m = \frac{P_a V_a}{R T_a} \text{ or } V_r = \frac{P_a V_a T_r}{R T_a}$$

$P_r$  =  $P$  - vapor pressure.

Assuming the air saturated in order to get an approximate value of  $P_r$ .

$$\text{vapor pressure at } T_r (117.5^\circ) \\ = 6.80 \quad P = 18.6$$

$$P_r = (18.6 - 6.8) \times 144 = 10290 \text{ #}$$



$$V_r = \frac{2047 \times 38.7 \times 638}{10290 \times 532} = 9.23$$

$$W_r = \text{weight of vapor per cu ft air} \\ = \frac{m_r}{V_r} = \frac{.0445}{9.23} = .00482$$

$$W_r \times T_r = Y_{\text{teat}} \times t_{\text{rat.}}$$

$$.00482 \times 638 = Y_{\text{teat}} \times t_{\text{rat.}}$$

From the steam tables it was found that the temperature of  $123^\circ$  & its  $Y$  gave a product nearly equal to  $.00482 \times 638$ .

This was low so  $125^\circ$  was tried, pressure = 1.93

$$P_r = (78.6 - 1.93) 144 = 11050$$

$$V_r = \frac{2047 \times 38.7 \times 638}{11050 \times 532} = 8.61$$

$$W_r = \frac{.0445}{8.61} = .00516$$

$$W_r \times T_r = .00516 \times 638 = 3.29$$

$$Y_{125^\circ} = .00557 \quad 125^\circ \text{ absolute} = 586$$

$$.00557 \times 586 = 3.27 = 3.29 \text{ nearly}$$

Since  $125^\circ = T_{\text{teat}} = \text{temp. feature in}$

$$H_r = m_r [q_{T_{\text{teat}}} + p_{T_{\text{teat}}} + .369(T_{\text{teat}} - T_{\text{teat}})]$$



$$= .0445 [93.1 + 962.9 + .369(177-125)] =$$

$$H_v = \underline{47.8} \text{ B.T.U.}$$

$$\begin{aligned} H_{hr} &= \text{heat of work done by air} \\ &\text{at high pressure} = \frac{(P_r - P_a) V_r}{778} \\ &= \frac{(11050 - 2047) 8.61}{778} = 99.5 \\ &= \underline{99.5} \end{aligned}$$

$$\begin{aligned} \text{Total heat put in} &= h_a + h_v + H_i \\ &= 13.53 + 46.5 + 242.5 = 302.53 \text{ B.T.U.} \end{aligned}$$

$$\begin{aligned} \text{Total heat accounted for} \\ &= H_a + H_v + H_w + H_{hr} \\ &= 66.7 + 47.8 + 81 + 99.5 \\ &= 295 \text{ B.T.U.} \end{aligned}$$

$$\begin{aligned} \text{Heat unaccounted for, lost by} \\ \text{radiation} &= 302.53 - 295 \\ &= \underline{7.5} \text{ B.T.U.} \end{aligned}$$

On account of the smallness of the clearance volume it was omitted in the calculation.



# Heat Balance of Second Test.

Method pg 47.

Symbols pg 17-18 - 47.

Values pg 37.

$$H_b = 29,7036$$

$$P_g = 29,7036 \times .7908 \times 144 \\ = 2100^{\#} \text{ per sq ft.}$$

$$V_a = 38.7 \text{ cu ft.}$$

$$R_1 = 100\%$$

$$T_o = 60^{\circ} \text{ absolute } 521$$

$$T_a = 70.9^{\circ} \text{ absolute } 532$$

$$R_2 = 98\% \quad (\text{1st test})$$

$$\mu_1 = .3725^{\#} \text{ per sq in}$$

$$\mu = .366 \quad (\text{1st test})$$

$$T_s = 70.5^{\circ} \quad "$$

$$P_a = 2047^{\#} \quad "$$

$$h_a = \underline{13.53} \text{ B.T.U. } (\text{1st test})$$

$$h_v = \underline{45.5} \text{ B.T.U. } (\text{1st test})$$



$$H_w - t_w = 72^\circ \quad t_w' = 88.1^\circ$$

$$(56.1 - 40.1) 8.09 = 129.33 \text{ B.T.U.}$$

$$\text{or } (56.1 - 40.1) 4.14 = 66.24 \text{ B.T.U.}$$

Note, - On page 38 are given two values of  $m_w$  corresponding to the two times given in the column under "Time Tank" in Table 5. The time 1 hr. 37 min. was the time recorded. The time 1 hr 7 min is probably correct for three reasons, - 1<sup>st</sup> It was remembered that the time and weight of the tank empty of the second test was taken almost immediately after the time and



weight full of the  
 first test viz 1 hr 3.5 min.  
 2<sup>nd</sup> The water throttle  
 was not changed from  
 the second to the third  
 test and the third test  
 gives  $m_w = 4.13^{\text{th}}$  3<sup>rd</sup> The  
 water was throttled  
 down slightly from the  
 first to the second test  
 and the first gave  
 $m_w = 5^{\text{th}}$  So that a value  
 of  $m_w = 8.09^{\text{th}}$  as given  
 by the first time is quite  
 out of the question. The  
 value

$H_w = \underline{66.24 \text{ B.T.U.}}$  will therefore  
 be used.

$$H_c = 0$$

$$H_i = \frac{522 \times 33000}{778} = 222 \text{ B.T.U.}$$



$$H_i = \underline{222} \text{ B.T.U.}$$

$$H_a = \frac{2047 \times 38.7}{532 \times .41 \times 778} (631 - 493) \\ = \underline{64.4} \text{ B.T.U.}$$

$$H_v - m_v = .0445^{\#} \text{ (1st test)}$$

$$T_r = 170.6$$

$$Pr(\text{first value}) = (58.9 - 6) \times 144 \\ = 7610$$

$$V_r(\text{first value}) = \frac{2047 \times 38.7 \times 631}{7610 \times 532} \\ = 13.14$$

$$W_r(\text{first value}) = \frac{.0445}{13.14} = .00337$$

$$.00337 \times 631 = \gamma_{110^{\circ}} \times (461 + 110) \\ \text{nearby.}$$

$$\text{Taking } 114^{\circ} = t_{\text{sat.}}$$

$$\text{pressure} = 1.42^{\#}$$

$$\gamma = .004168$$

$$Pr = (58.9 - 1.42) 144 = 8270$$

$$V_r = \frac{2047 \times 38.7 \times 631}{8270 \times 532} = 11.625$$

$$W_r = \frac{.0445}{11.625} = .00383$$



$$.00383 \times 631 = 2.41$$

$$575 \times .004168 = 2.40$$

$$2.41 = 2.40 \text{ nearly}$$

$$t_{\text{sat}} = 114$$

$$H_v = .00445 [82 + 971.6 + 369(170.6 - 114)]$$

$$= \underline{47.6}$$

$$H_{pr} = \frac{(8270 - 2047) 11.625}{778} = 92.9$$

$$= \underline{92.9} \text{ B.T.U.}$$

Total heat accounted for,

$$13.53 + 45.5 + 222 = \underline{281.63}$$

Total heat accounted for,

$$64.4 + 47.6 + 66.72 + 92.9$$

$$= \underline{271.1}$$

Heat unaccounted for, due to radiation

$$281.63 - 271.1 = \underline{\underline{10.53}} \text{ B.T.U.}$$



# Heat Balance Third Test.

Method pg 47

Symbols pg 17-18-47.

Values pg. 41

$$H_g = 29.696$$

$$P_b = 4908 \times 29.696 \times 144 = 2100^{\#}$$

$$V_a = 38.7 \text{ cu ft (1st test)}$$

$$R_1 = 100\%$$

$$T_0 = 60.4^{\circ} \text{ absolute} = 521^{\circ}$$

$$T_a = 71^{\circ} \text{ absolute} = 532^{\circ}$$

$$R_2 = 98\%$$

$$h_1 = .3726^{\#}$$

$$h = .365^{\#} \quad 98\% \text{ of } .3726$$

$$T_s = 70.4$$

$$P_a = 2100 - (144 \times .365) = 2047^{\#}$$

$$H_a = \underline{13.53} \text{ B.T.U.}$$

$$h_v = 38.7 \times .001145 \left[ 38.5 + 1006 \right. \\ \left. + .369 (70.9 - 70.4) \right]$$

$$= \underline{46.3} \text{ B.T.U.}$$



$$H_w - t_w = 73^\circ \quad t_w' = 91.4^\circ$$

$$(59.4 - 41.1) 4.13 =$$

$$\underline{75.5} \text{ B.T.O.}$$

$$H_e = 0$$

$$H_i = \frac{5.59 \times 33000}{778} =$$

$$\underline{237} \text{ B.T.O.}$$

$$H_a - T_a = 177^\circ$$

$$\frac{2047 \times 38.7}{532 \times 41 \times 778} (638 - 493)$$

$$= \underline{67.6}$$

$$H_r - m_r = 38.7 \times .001145$$

$$= .0445$$

$$P_r \text{ (first value)}$$

$$(71.7 - 7.01) 144 = 9310^\circ$$

$$V_r \text{ (first value)}$$

$$\frac{2047 \times 38.7 \times 638}{9310 \times 532}$$

$$= 10.2$$

$$W_r \text{ (first value)} = \frac{.0444}{10.2}$$

$$= .00435$$

$$638^\circ \times .00435 = \text{nearly } 2.77 \times (461 + 119)$$

$$\text{Trying } 122^\circ = t_{\text{test abe.}} = 583$$



$$X_{122} = .005156 \text{ pressure} = 1.779$$

$$P_r = \frac{(71.7 - 1.779) 144}{2047 \times 38.7 \times 638} = 10050$$

$$V_r = \frac{10050 \times 532}{9.46}$$

$$= 9.46$$

$$W_r = \frac{.0444}{9.46} = .00469$$

$$.00469 \times 638 = 2.99$$

$$.005156 \times 583 = 3.00$$

$$3.00 = 2.99 \text{ nearly}$$

$$t_{\text{sat}} = 122^\circ$$

$$H_r = .0444 [90.1 + 965.3 + .369(177 - 122)]$$

$$= 47.6$$

$$H_{pr} = \frac{(10050 - 2047) 9.46}{778}$$

$$= 97.2$$

Total heat put in -

$$13.53 + 46.3 + 237 = \underline{296.83 \text{ B.T.U.}}$$

Total heat accounted for, -

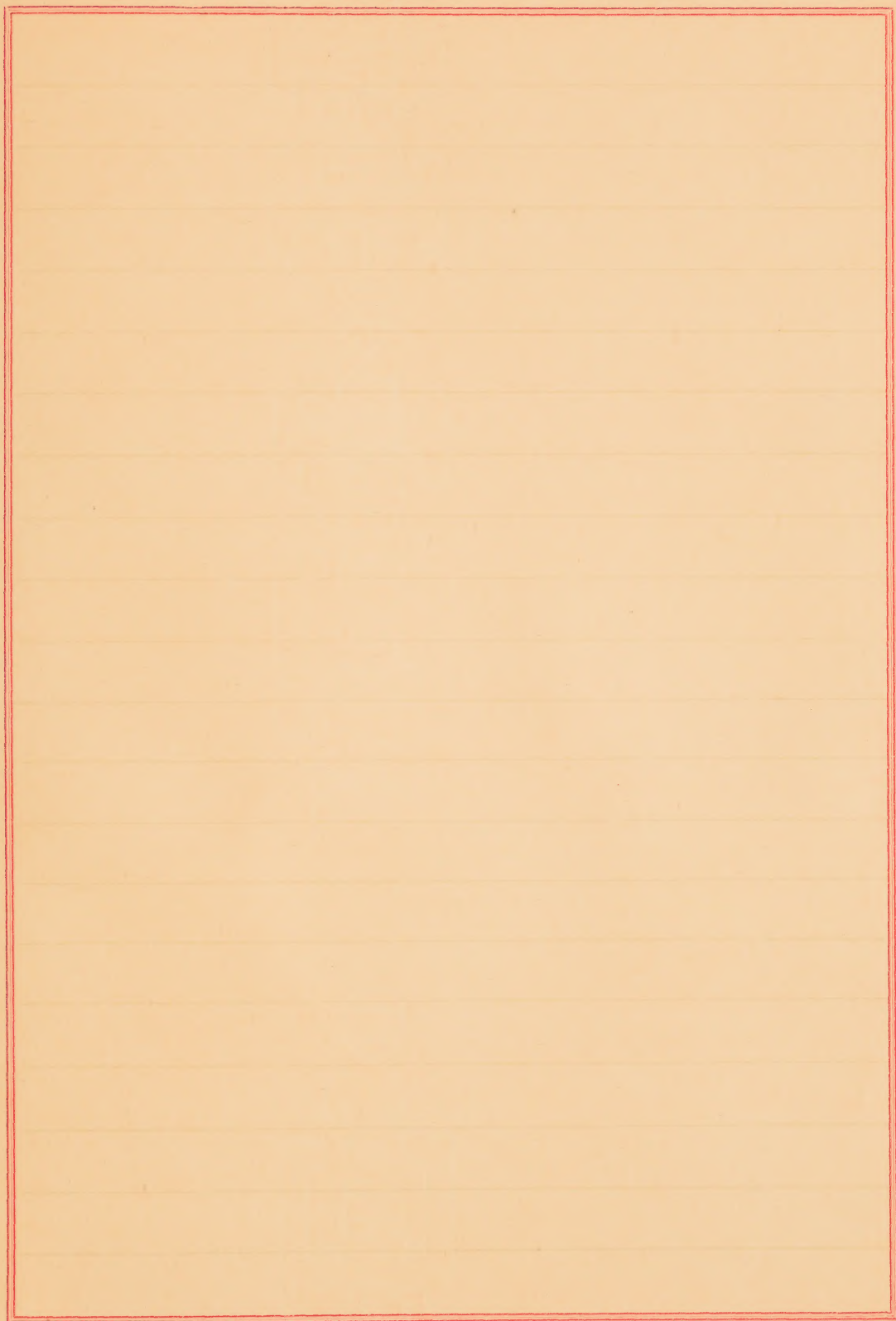
$$67.6 + 75.5 + 47.6 + 97.2$$

$$= \underline{287.9}$$

Heat unaccounted for -

$$296.83 - 287.9 = \underline{8.93 \text{ B.T.U.}}$$









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